

The Gastropods in the Streams and Rivers of Five Fiji Islands: Vanua Levu, Ovalau, Gau, Kadavu, and Taveuni

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Abstract. Streams and rivers on the islands of Vanua Levu, Ovalau, Gau, Kadavu, and Taveuni, Fiji, were investigated for gastropods, water conductivity, water hardness, temperature, substrate, and current speed during 1983 and 1984. As at other Indo-Pacific islands there was a diverse and abundant lotic gastropod fauna. Twenty-six species were collected on Vanua Levu and 13-16 species were found in each torrential stream studied on the other four islands. Upstream, above the influence of the tide, both the longitudinal and horizontal distributions of gastropods appeared to be mainly dependent on the water speed and type of substrate. A suspected new species of *Acochlidium* (Opisthobranchia) was discovered on the island of Vanua Levu.

INTRODUCTION

Land and freshwater mollusks were first collected by Graeffe from the Fiji islands of Viti Levu, Ovalau, Motiriki, Ngara, Kadavu, Vanua Balavu, Mago, Kanacea, and Cikobia-i-lau, and were described by MOUSSON in 1870. More recently the freshwater gastropods on Viti Levu have been investigated by STARMÜHLNER (1976) and HAYNES (1985) but nothing has been written about gastropods on the other islands since 1870.

This investigation was aimed at finding what freshwater gastropods were present on the high islands of Vanua Levu, Ovalau, Gau, Kadavu, and Taveuni. Physical factors and water chemistry were also measured in order to see how much these factors contributed to the distributions of the gastropods.

STUDY AREA

The islands investigated are shown in Figure 1. Vanua Levu, the second largest island of the group, rises about 1000 m above sea level and has extensive areas on the northern side where sugar cane is grown, while on the wetter southern side there are many coconut plantations.

The four smaller volcanic islands (Ovalau, Gau, Kadavu, and Taveuni) rise steeply to an altitude of 400-500 m. Their high central regions are covered mainly in rain forest, while there are many villages and village gardens

containing dalo (*Colocasis esculenta*), cassava (*Manihot esculenta*), paw paw (*Carica papaya*), banana (*Musa paradisiaca*), and yoqona (*Piper methysticum*) in the coastal areas. Some coconut plantations are found on Ovalau and Taveuni. The torrential streams on these islands are liable to sudden flooding and occasionally they become dry in their lower courses. The substrate of the streams is composed of large rocks and boulders so that the water flows in a series of short waterfalls, pools, and white cascades. Macrophytes were absent except 300-400 m upstream from the mouth at the sides of Naivika Creek, Taveuni, where watercress (*Nasturtium officinale*) grew.

All five islands were formed from volcanic eruptions in Miocene and late Pliocene times while Taveuni is the site of the most recent (1200 AD) volcanic activity in the Fiji group (RICKARD, 1966; IBBOTSON, 1961; WOODROW, 1980).

MATERIALS AND METHODS

Vanua Levu

Gastropods were collected from rivers and streams in October 1983. The stations, 1-10 on the map (Figure 1), were chosen to be as representative as possible while still being accessible by road.

The substrate at each station was searched for 30 min for gastropods. The leaf litter, plants, wood, and upper and lower surfaces of stones and boulders were inspected



Figure 1

A map of the main islands of Fiji showing the localities of the sampling stations on Vanua Levu and the positions of the streams that were sampled on Ovalau, Gau, Kadavu, and Taveuni.

and the sand and gravel were sieved. Samples of each species at all the stations were taken to the laboratory and identified according to RIECH (1937), STARMÜHLNER (1970, 1976), and HAYNES (1984).

The substrate, water speed, and temperature were noted and water samples were taken at most stations. The water samples were analyzed for conductivity (μS) and hardness ($\text{mg CaCO}_3/\text{L}$) by the Institute of Natural Resources, University of the South Pacific.

Ovalau, Gau, Kadavu, and Taveuni

Physical parameters were noted and water samples and gastropods were collected in 1983–1984 by the methods

described above. A stream on each island was sampled from the mouth to 2000 m inland at four stations (three stations on Kadavu). The streams sampled were Rukuruku Creek, Ovalau; Navure Creek, Gau; Nubulevu Creek, Kadavu; and Naivika Creek, Taveuni (Figure 1).

Several of each species of gastropod were dissected and the contents of the guts were examined to find what food they had been eating.

RESULTS

Specimens of the prosobranchs collected in this survey were deposited in the Los Angeles County Museum of Natural History and duplicate specimens are available at the School

of Pure and Applied Sciences, University of the South Pacific, Suva, while specimens of the suspected new species of *Acochlidium* were sent to the Vienna Natural History Museum.

Vanua Levu

The physical and chemical conditions and gastropods present at each station are shown in Table 1. The nomenclature of STARMÜHLNER (1970, 1976) has been used where possible. A total of 26 species of gastropods was found on Vanua Levu, and all except two were prosobranchs. These exceptions were *Physastra nasuta* (LACM 83-135.1) (Pulmonata, Planorbiiidae) and *Acochlidium* sp. (Opisthobranchia, Acochlididae). Of the Prosobranchia, 12 (*Neritina pulligera* [LACM 84-174.1], *N. squamipicta* [LACM 83-139.1], *N. auriculata* [LACM 84-170.1], *N. turtoni* [LACM 83-140.1], *N. canalis* [LACM 84-171.1], *N. petiti* [LACM 84-173.2], *N. porcata* [LACM 84-168.1], *Neritilia rubida* [LACM 83-136.1], *Clithon diadema* [LACM 83-142.1], *C. olivaceus* [LACM 83-145.1], *C. pritchardi* [as *C. corona* in HAYNES, 1984] [LACM 83-143.1], *C. oualaniensis* [LACM 84-172.1]) belong to Neritidae, 8 (*Melanoides tuberculata* [LACM 83-141.1], *M. lutosa* [LACM 83-145.2], *M. plicaria* [LACM 83-137.1], *M. aspirans* [LACM 83-138.1], *Thiara bellicosa* [LACM 83-142.3], *T. scabra*, *T. terpsichore* [LACM 83-142.2], *T. amarula* [LACM 83-144.1]) belong to Thiariidae, and 4 (*Septaria lineata* [LACM 83-142.4], *S. suffreni* [LACM 84-174.3], *S. porcellana* [LACM 84-173.3], *S. sanguisuga* [as *S. borbonica* in HAYNES, 1984] [LACM 84-174.2]) belong to Septariidae (Neritacea).

Physastra nasuta was found only on the northern side of the island (Stations 1–4, Figure 1), while *Acochlidium* sp. was discovered only at Station 6. Station 6 was also where the greatest number of species (11) were found. In general more species (6–11) were present in the rivers and streams on the steeper southern coast compared with those (3–6) on the flatter more cultivated northern coast (Figure 1).

The values for total ions (916 μS) and hardness (252 mg CaCO_3/L) were higher at Station 3 than at any other station, probably because of nearby limestone rock (RICKARD, 1966). At this station a green sponge encrusted boulders and stones. In the Dreketi-Seaqaqa river system (Stations 1–4) the temperature (30, 28, 28, 27°C) decreased as the distance from the sea increased (3, 6, 26, 33 km) (Table 1).

The temperatures at Stations 8 and 9 were lower than at other stations probably because measurements were taken earlier in the morning.

In the Dreketi-Seaqaqa river system (Stations 1–4) at Stations 1, 3, and 4, where the current was between 20 and 40 cm/sec, the gastropods *Physastra nasuta*, *Melanoides tuberculata*, and *Neritina pulligera* were found (Table 1). The inland or high altitude species *Melanoides lutosa* appeared at Station 3 (26 km upstream) and was also present at Station 4. *Septaria porcellana* and *S. suffreni* were present

on the boulders at Station 3 but had not reached the stream at Station 4. The Dreketi River, where Station 2 was located, was wide and deep and the current slow; consequently, three different gastropods, *Thiara bellicosa*, *Neritilia rubida*, and *Clithon diadema*, were found at this station (Table 1).

Ovalau, Gau, Kadavu, and Taveuni

The physical and chemical conditions that existed and the gastropods that were present in the four sampled streams are recorded in Table 2. The number of species in each stream was approximately the same. There were 16 species in Rukuruku Creek, Ovalau, 15 in Navure Creek, Gau, 15 in Nubulevu Creek, Kadavu, and only 14 in Naiviki Creek, Taveuni, where the calcium content of the water was low (9 mg CaCO_3/L).

Generally the same gastropods were found in the streams of the four islands. From the mouth to 20 m upstream, only species that are able to live in brackish water were present (Table 2). Further upstream (300–400 m) in fairly swift currents, some of these species persisted, e.g., *Clithon oualaniensis*, *C. diadema*, *C. pritchardi*, and *Septaria porcellana*. Of these, however, only *C. pritchardi* and *S. porcellana* were found 1500 m or more upstream (Table 2). These higher, steeper parts of the streams were rich in gastropod species (5–11 species) and in numbers of individuals (up to 125/m²). *Melanoides tuberculata* and *M. lutosa* were usually found in quieter parts of the stream, while species such as *Clithon olivaceus*, *C. pritchardi*, *Neritina variegata* (LACM 84-169.1), and *N. canalis* were found on the sides or on the under surface of rocks; the limpets *Septaria* spp. were able to live on the upper surfaces as well as the sides of rocks (Figure 2).

The course of Rukuruku Creek rose less steeply for the first 500 m than did that of the other three streams. Consequently there was greater diversity of gastropod species at 300–400 m upstream, because those favoring a less swift current (e.g., *Thiara amarula* and *Neritina squamipicta*) were able to survive.

When the stomachs of the various gastropod species were examined they were found to contain mainly unicellular green algae, diatoms, and filamentous cyanobacteria. Periphyton scraped from stones on which gastropods had been found contained similar microphytes.

In the torrential streams investigated, gastropods were the dominant benthic invertebrates. Insect larvae were absent from most parts of the streams. Prawns and fish were present in all streams, especially in pools below cascades.

The temperature, hardness, and total ions in the water of Rukuruku Creek, Ovalau, and Navure Creek, Gau, were similar (Table 2) but the water of Nubulevu Creek, Kadavu, had a slightly higher value for total ions (160 compared with 122 and 147 μS) and was less hard (20 mg CaCO_3/L compared with 56 and 52). Naivika Creek, Taveuni, was low in calcium ions (9 mg CaCO_3/L) and total ions (36.1 μS). The temperature was significantly

Table 1

The physical conditions, results of water analysis, and gastropods present at the sampling stations on the island of Vanua Levu. ND = not determined.

Station	River & map reference, 1:250,000, Vanua Levu	Substrate	Distance from sea (km)	Water speed (cm/sec)	Temperature (°C)	Total ions (μS)	Hardness (mg CaCO ₃ /L)	Gastropods present
1	Creek into Dreketi R.: YG0365	stones	3 km	30-40	30	144.6	56	<i>Physastra nasuta</i> (Morelet), <i>Melanooides tuberculata</i> (Müller), <i>Neritina pulligera</i> (Linné)
2	Dreketi R. 2 km east of Nabavati: YG0866	sand & stones	6 km	10	28	141.4	40	<i>Thiara bellicosa</i> (Hinds), <i>Neritina rubida</i> (Pease), <i>Clithon diadema</i> (Récluz)
3	Seaqaqa R. near Naravuka turnoff: YG2462	stones & boulders	26 km	30	28	915	252	<i>Physastra nasuta</i> , <i>Melanooides lutosus</i> (Gould), <i>M. tuberculata</i> , <i>Neritina pulligera</i> , <i>Septaria porcellana</i> (Linné), <i>S. suffreni</i> (Récluz)
4	Stream into Seaqaqa R. at Salvou: YG2963	stones, boulders & rocks	33 km	20-30	27	ND	ND	<i>Physastra nasuta</i> , <i>Melanooides tuberculata</i> , <i>M. lutosus</i> , <i>Neritina pulligera</i>
5	Stream at Nabalebale: YG4156	gravel & stones	8 km	50-60	28	111.1	36	<i>Melanooides tuberculata</i> , <i>M. plicaria</i> (Born), <i>M. aspirans</i> (Hinds), <i>Thiara terpsichore</i> (Gould), <i>Clithon olivaceus</i> (Récluz), <i>C. pritchardi</i> (Dohrn), <i>Neritina pulligera</i> , <i>Septaria porcellana</i> , <i>S. suffreni</i>
6	Nasekawa R. at Venivesi: YG4355	stones	7 km	10-30	29	123.7	40	<i>Melanooides tuberculata</i> , <i>M. aspirans</i> , <i>Clithon olivaceus</i> , <i>Neritina canalis</i>
7	Nakelikosa Ck.: YG5342	gravel & rocks	20 m	10	28	697	136	Sowerby, <i>N. petiti</i> Récluz, <i>N. porcata</i> Gould, <i>Septaria sanguisuga</i> (Reeve), <i>S. porcellana</i>
8	Creek on Hibiscus Hwy.: YG8848	sand & rocks	500 m	10	22	292	64	<i>Melanooides aspirans</i> , <i>Clithon pritchardi</i> , <i>Neritina auriculata</i> Lamarek, <i>N. squamipicta</i>
9	Bagasau Ck.: YG9252	rocks & boulders	2 km	0-50	25	287	100	<i>Melanooides tuberculata</i> , <i>Clithon pritchardi</i> , <i>C. diadema</i> , <i>Neritina turtoni</i> (Récluz), <i>N. auriculata</i> , <i>N. squamipicta</i> , <i>Septaria porcellana</i> , <i>S. lineata</i>
10	Buca Ck.: ZG0457	gravel, rocks & wood	50 m	0-20	28	257	72	<i>Melanooides tuberculata</i> , <i>M. aspirans</i> , <i>Clithon olivaceus</i> , <i>Neritina canalis</i> Sowerby, <i>N. petiti</i> Récluz, <i>N. porcata</i> , <i>Septaria sanguisuga</i> , <i>S. porcellana</i>

Table 2

The physical conditions, results of water analysis, and gastropods present at four (three on Kadavu) sampling stations in a stream on each of the islands of Ovalau, Gau, Kadavu, and Taveuni. ND = not determined.

	Rukuruku Ck. Ovalau	Navure Ck. Gau	Nubulevu Ck. Kadavu	Naivika Ck. Taveuni
Mouth-20 m upstream				
Current speed (cm/sec)	0-10	0-10	0-10	0-10
Temperature (°C)	26	27	27	22
Hardness (mg CaCO ₃ /L)	190	180	110	330
Conductivity (μS)	2100	1330	1820	6280
Species	<i>Clithon rarispina</i> (Mousson), <i>C. pritchardi</i> , <i>C. diadema</i> , <i>C. oualaniensis</i>	<i>Clithon diadema</i> , <i>C. oualaniensis</i>	<i>Clithon pritchardi</i> , <i>Neritina auriculata</i>	<i>Clithon diadema</i> , <i>C. oualaniensis</i> , <i>C. pritchardi</i> , <i>Neritina auriculata</i> , <i>Septaria porcellana</i>
300-400 m upstream				
Current speed (cm/sec)	0-50	30-40	0-40	20-30
Temperature (°C)	25.5	26	26	22
Hardness (mg CaCO ₃ /L)	56	52	20	19.67
Conductivity (μS)	147.1	122	160	66.7
Species	<i>Clithon oualaniensis</i> , <i>C. diadema</i> , <i>C. pritchardi</i> , <i>Neritina pulligera</i> , <i>N. canalis</i> , <i>N. squamipicta</i> , <i>Melanoides aspirans</i> , <i>M. plicaria</i> , <i>M. tuberculata</i> , <i>Thiara amarula</i> (Linné), <i>Septaria porcellana</i>	<i>Clithon diadema</i> , <i>C. pritchardi</i> , <i>Neritina turrata</i> (Gmelin), <i>Melanoides aspirans</i>	<i>Clithon pritchardi</i> , <i>C. olivaceus</i> , <i>Neritina petiti</i> , <i>N. porcata</i> , <i>Septaria macrocephala</i> (Guillon), <i>S. porcellana</i>	<i>Neritina canalis</i> , <i>N. variegata</i> (Lesson), <i>Melanoides aspirans</i> , <i>M. tuberculata</i> , <i>S. porcellana</i>
1000-1100 m upstream				
Current speed (cm/sec)	0-100	0-80	0-100	50-100
Temperature (°C)	25	25	26	22
Hardness (mg CaCO ₃ /L)	58	55	20	9
Conductivity (μS)	149.8	134	159	36.1
Species	<i>Clithon olivaceus</i> , <i>Melanoides lutosus</i> , <i>M. tuberculata</i> , <i>Septaria porcellana</i> , <i>S. suffreni</i>	<i>Clithon olivaceus</i> , <i>C. pritchardi</i> , <i>Neritina variegata</i> , <i>N. canalis</i> , <i>N. petiti</i> , <i>N. macgillivrayi</i> (Reeve), <i>Melanoides aspirans</i> , <i>Septaria porcellana</i> , <i>S. sanguisuga</i> , <i>S. suffreni</i>	<i>Clithon olivaceus</i> , <i>C. pritchardi</i> , <i>Neritina variegata</i> , <i>N. canalis</i> , <i>N. pulligera</i> , <i>Melanoides arthurii</i> (Brott), <i>M. tuberculata</i> , <i>Septaria porcellana</i> , <i>S. suffreni</i> , <i>S. macrocephala</i> , <i>S. sanguisuga</i>	<i>Clithon olivaceus</i> , <i>Neritina variegata</i> , <i>Melanoides arthurii</i> , <i>M. tuberculata</i> , <i>Septaria suffreni</i> , <i>S. porcellana</i> , <i>S. macrocephala</i> , <i>S. sanguisuga</i>
2000 m upstream (side stream)				
Current speed (cm/sec)	20-40	40-60	ND	50-100
Temperature (°C)	25	ND	ND	21
Hardness (mg CaCO ₃ /L)	60	ND	ND	9.0
Conductivity (μS)	152.3	ND	ND	36.1
Species	<i>Clithon olivaceus</i> , <i>Melanoides lutosus</i> , <i>M. tuberculata</i>	<i>Clithon olivaceus</i> , <i>Neritina pulligera</i> , <i>N. petiti</i> , <i>N. canalis</i> , <i>N. variegata</i> , <i>N. porcata</i> , <i>Septaria porcellana</i> , <i>S. suffreni</i> , <i>S. sanguisuga</i>	ND ND	<i>Clithon olivaceus</i> , <i>Neritina variegata</i> , <i>Septaria porcellana</i>

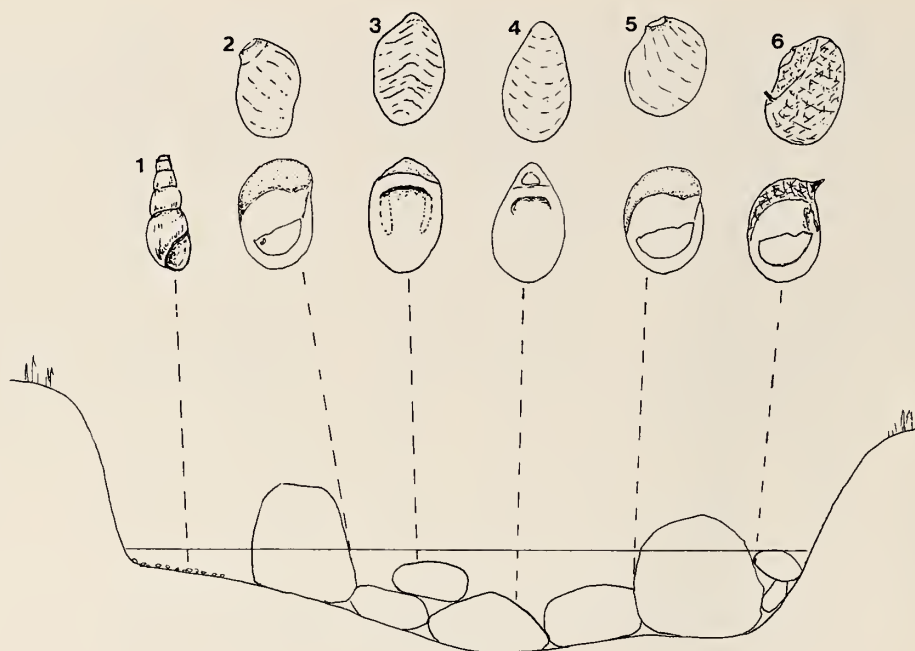


Figure 2

The distribution of gastropods across a Fijian torrential stream showing the different habitats of the various shell types. 1, *Melanooides lutosus*; 2, *Neritina variegata*; 3, *Septaria porcellana*, 4, *S. sanguisuga*; 5, *Clithon olivaceus*; 6, *C. pritchardi*.

lower (21–22°C) than that of the other three streams (25–27°C) ($P < 0.01$). Above the brackish water region of the streams there was little difference in the chemical composition along the length of each stream.

DISCUSSION

Twenty-six species of gastropods were found on Vanua Levu at 10 stations compared with 32 species from 47 stations on Viti Levu (HAYNES, 1985). Species present on Viti Levu but not found on Vanua Levu were *Planorbarius corneus*, *Ferrissia noumeensis*, *Gyraulus montrouzieri*, *Assimineia crosseana*, *Melanooides arthurii*, *Fluviopupa pupoidea*, and *Fijidoma maculata*. The endemic species *Fluviopupa pupoidea* Pilsbry and *Fijidoma maculata* (Mousson), which are found in the headwaters of the rivers of Viti Levu, were not found on any of the five islands. These two species may be remnants of an old fauna that has survived only on the geologically older Viti Levu (LADD, 1934).

Some species (*Clithon olivaceus*, *Neritina variegata*, *Septaria macrocephala* [LACM 84-169.3], and *S. sanguisuga*) were absent from all collecting stations on Viti Levu (HAYNES, 1985) but were present on the four smaller islands. *Clithon olivaceus* and *S. sanguisuga* were also found on Vanua Levu. It is difficult to judge whether these species have always been absent from streams on Viti Levu or whether they have recently disappeared because logging operations have increased the turbidity of the water. Sev-

eral *Thiara* spp. (e.g., *Thiara bellicosa* and *T. terpsichore*) were found on Vanua Levu and Viti Levu (HAYNES, 1985) but not in the torrential streams. This was probably because they have failed to become established in the swift currents of these streams.

The small (10–15 mm long) shell-less opisthobranch *Acochlidium* sp. was found only at Station 6 on Vanua Levu. It is thought to be an undescribed species and specimens have been sent to E. Wawra, Naturhistorisches Museum Wien. It is somewhat similar to *Acochlidium bayerfehlmanni* Wawra from the Palau Islands (WAWRA, 1980) and *Acochlidium sutteri* Wawra from Sumba, Indonesia (WAWRA, 1979).

A feature of many streams in Fiji is the richness and abundance of gastropod species. In contrast, islands in the Caribbean region appear to have many more rheolite insect species than gastropod species. HARRISON & RANKIN (1976) found 14 insect species and no gastropod species in high-level streams (290–488 m altitude) on St. Vincent (Lesser Antilles) and 15 insect species and 3 gastropod species in low-level streams (8–274 m altitude). STARMÜHLNER & THEREZIEN (1983) found only one lotic gastropod species (*Neritina punctulata*) but over 20 species of insects in streams on Guadeloupe, Dominica, and Martinique.

However, other islands in the Indo-Pacific region appear to have a rich gastropod fauna similar to that found in the Fiji Islands. STARMÜHLNER (1982) described 16

gastropod species in running water on Andaman Island, Indian Ocean. These include *Melanoides tuberculata*, *M. plicaria*, *Thiara scabra*, *Neritina pulligera*, *N. variegata*, *N. squamipicta*, *Septaria porcellana*, and *Neritilia rubida*, which are also present in Fijian streams and rivers. The mountain streams of New Caledonia had at least 16 species of gastropods and those of Sri Lanka 13 gastropod species (STARMÜHLNER, 1979).

Likely predators in the slower streams and rivers of Vanua Levu were odonatid nymphs, coleopterid larvae, leeches, fishes, and cane toads (*Bufo marinus*) but in the torrential streams, because of the scarcity of rheolite insects, the only obvious predators were fish species.

Thiarid species (*Melanoides* spp. and *Thiara* spp.) are viviparous, and almost all are exclusively parthenogenetic, although a few dioecious populations have been found (DAVIS, 1971). Those species (e.g., *Melanoides tuberculata* and *M. lutosa*) that live far inland give birth to juvenile adults, while species (e.g., *M. aspirans* and *M. plicaria*) that inhabit tidal regions release veligers into the water (STARMÜHLNER, 1976).

The neritid snails (*Neritina* spp., *Clithon* spp., and *Septaria* spp.) are dioecious. After copulation the females lay eggs in egg cases that they cement to stones, boulders, and often to shells of other gastropods. It is not known for most species whether the young hatch as veligers or as juvenile snails. GOVINDAN & NATARAJAN (1972) reported that eggs of the lowland Indian species *Neritina layardi* (Lesson) hatched as veligers after 20–22 days and those of *Septaria tessellata* (= *S. lineata* Lamarck) hatched as veligers after 14–15 days. FORD (1979) reported that the eggs of the Hawaiian torrential stream species *Neritina granosa* Sowerby also hatched as veligers. Ford believed that after hatching the veligers of *N. granosa* were swept out to sea and later settled at the mouth of rivers or streams. FORD (1979) observed long chains of up to 80 young snails (less than 5 mm high) moving upstream. No such phenomenon has been observed in Fiji streams but small juveniles (1.5–2.0 mm high) have been found clinging to the shells of adult *Septaria* spp. and *Clithon* spp. 2 km upstream from the mouth. These species likely either hatch as juvenile snails or as veligers that settle in freshwater.

Certain species (e.g., *Neritina auriculata*, *N. turrita*, and *Clithon diadema*) were confined to brackish or tidal regions where total ions were high. Above the influence of the tide, the water speed, and consequently the nature of the substrate, appeared to determine the distribution of gastropods both along and across the stream. However, it is possible that the absence of *Neritina pulligera* and *Neritina petiti* from Naivika Creek, Taveuni, was caused by low amounts of dissolved ions in the water.

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